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SATURN V/APOLLO SUBORBITAL ABORT TRAJECTORIES USING S-IVB OR SM PROPULSION (U)

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ABSTRACT

The use of the S-IVB and SM propulsion systems for trajectory modification following abort of a Saturn V/Apollo launch into earth orbit has been investigated. Two modes of operation are included in the study: (1) direct entry into the atmosphere after the impact point of the CM has been altered by using the S-IVB or SM propulsion, (2) continuation into a parking orbit using one of these propulsion systems. In the first mode, minimum and maximum distances of the CM impact point from Cape Kennedy are obtained as a function of the time of abort. From this data the smallest possible number of recovery points is determined. In the second mode of operation, the earliest time at which orbit can be attained by using the S-IVB or SM following premature termination of the S-II stage engines is determined.

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SATURN V/APOLLO SUBORBITAL ABORT TRAJECTORIES

USING S-IVB OR SM PROPULSION

1.0 PURPOSE AND SCOPE

The primary purpose of this study is to investigate the performance of the S-IVB and SM as maneuvering stages during suborbital aborts of the Saturn V/Apollo vehicle. The propulsion systems would be used in order to provide flexibility in landing point selection while at the same time assuring acceptable entry conditions. If the propulsive maneuvering capability of the S-IVB or SM stage and/or the aerodynamic maneuvering capability of the CM is sufficiently great, the dispersal of recovery forces might be simplified by locating them in one or more predetermined abort recovery areas.

An earlier study (Reference 1) was concerned with direct entry following vacuum abort of a Saturn V/Apollo launch without use of propulsion. The results of that study indicated that entry conditions are always such that the aerodynamic loads are within safe limits, but that the maneuvering capability of the CM is not adequate to restrict the impact point following abort to a relatively small number of recovery areas. It is of interest, therefore, to determine what degree of maneuverability can be obtained by using SM or S-IVB propulsion.

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2.0 INTRODUCTION

Saturn/Apollo flight vehicles will have, at least theoretically, a much greater degree of maneuverability in vacuum abort operations than is possible in Atlas/Mercury and Titan/Gemini flights. This is because of the substantial propulsion capability provided for Saturn/Apollo vehicles beyond that required to achieve earth orbit. Whereas the Mercury space capsule had about 400 fps ΔV available from its retrorockets for abort maneuvering and the Gemini will have about 550 - 700 fps available from its maneuvering rockets, the Apollo has a capability of almost 11,000 fps with the SM at any time during launch, or almost 13,400 fps with the S-IVB stage at any time prior to the S-II stage shutdown time. Thus, there is the possibility that one of these stages can be used in the event of an abort to enable the CM to impact at one of perhaps several selected points. This could be accomplished in one of two ways: (1) the impact point is altered to coincide with a preselected point (or within a preselected area) by increasing or decreasing the ballistic range appropriately or (2) rather than entering the atmosphere directly, the vehicle continues into earth parking orbit and then deorbits whenever a desired landing site falls within range.

This study has been carried out, therefore, to obtain preliminary determinations of the Saturn V/Apollo vehicle capabilities for these two modes of operation, using either the S-IVB or SM stages.

Final determination of which mode and which stage should be used in abort situations will depend on more than the performance results reported herein. Factors such as the nature of the emergency, the speed with which it can be detected, stage separation and ignition problems, and guidance and control considerations will all enter into the final evaluation.

3.0 SUMMARY

The minimum and maximum possible ranges of the CM impact point using constant pitch attitude thrust programs and constant L/D entries were determined. In addition, the earliest point along a nominal launch trajectory from which a 100 nautical mile circular orbit can be attained using only the S-IVB or SM propulsion was determined. The results (based upon certain assumptions which are detailed in the section, "Analysis and Results") are summarized as follows:

(1) The performance of the S-IVB as a maneuvering stage during suborbital abort is superior to that of the SM because of a greater available ΔV and higher thrust-to-weight ratio.

(2) Using the S-IVB for direct entries following an abort, it is theoretically possible for the CM to reach a single impact point

if an abort is initiated any time between nominal S-II ignition plus 30 seconds (which is tentatively the time for LES jettison) and nominal S-II cutoff time. A second point would suffice for direct entry following aborts initiated during the time period of the S-IVB nominal first burn. Thus, a total of two recovery points is indicated.

(3) If the SM alone is used for direct entry following aborts during either S-II burn or S-IVB first burn, a total of at least five recovery points is necessary.

(4) A 100 nautical mile circular orbit can be attained using the S-IVB any time after approximately 407 seconds or using the SM after about 488 seconds of a nominal launch trajectory.

(5) Suborbital aborts can be restricted to posigrade maneuvers at all times while still requiring only two recovery points if direct entry with the S-IVB is used prior to t = 520 seconds and continuation into parking orbit with either the S-IVB or SM subsequent to that time.

(6) For direct entry trajectories, the variation of impact point with pitch angle during burning is sufficiently small so as to suggest the possibility of open loop control.

4.0 ANALYSIS

4.1 Configurations, Weights, and Engine Performance

The Saturn V/Apollo vehicle is assumed to be in the LOR mission configuration at launch. At the time the vacuum abort trajectory is started, everything below the maneuvering stage is assumed to have been jettisoned. Thus, when the S-IVB is used, the IU, LEM SM and CM remain attached to the S-IVB; when the SM is used as the maneuvering stage, only the CM is attached.

The assumed weights and engine performance are given in the following table:

	Maneuvering Stage	
	S-IVB	SM
Gross weight at beginning of powered abort, lbs.	350,750	59,500
Usable propellant weight, lbs.	219,000	39,500
Thrust lbs.	200,000	21,300
Specific impulse	424	310
Ideal ΔV, fps	13,400	10,900

These data do not reflect the latest weight and performance status; however, for the purposes of a preliminary performance study such as the present one, precise values are not necessary.

4.2 Initial Conditions at Abort

The Saturn V/Apollo vehicle is assumed to be on an 88° azimuth nominal LOR mission launch trajectory (STL Issue Zero Reference Trajectory) at the time of abort. The position and velocity vectors on this nominal launch trajectory become the initial conditions for the abort trajectory.

In most cases, it was assumed that the SM/CM could be separated from the launch vehicle and the SM main engine ignited with no time delay. The S-IVB, however, requires a chilldown prior to ignition; therefore, for the purposes of comparing it with the SM on a performance basis, a ten-second ignition delay was assumed. Actual in-flight chilldown time may be less than 5 seconds.

These assumptions include no time delay to account for separation and re-orientation. However, some cases were run using a sixty second coast prior to ignition to evaluate the resulting effects.

4.3 Control Programs

Relatively simple control programs were used in the trajectory studies. For the direct entry type of powered vacuum trajectories, constant pitch angle was used as the thrust vector control. Thus, for each time of abort, a one parameter family of vacuum abort trajectories was generated. Most of the cases studied used

constant pitch angle with respect to the local horizon; some cases were also run using a space-fixed pitch angle for comparison. An (L/D) maximum of 0.5 and W/C_DA of 75 lbs/ft^2 were assumed for the CM. Entry trajectories were calculated on the basis of constant L/D; therefore, the maximum range entries are simply those using L/D = (L/D) maximum, and minimum range are those using an L/D large enough to insure a peak aerodynamic load factor of no more than 10 g's.

In studying continuation into parking orbit following abort, the linear-tangent pitch control program (tangent Ψ = A+Bt) was used rather than a true optimum program. The parameters A and B and the thrust cutoff time, t_f, were iteratively adjusted so that the values of velocity, flight path angle and altitude at cutoff correspond to a 100 nautical mile circular orbit.

5.0 RESULTS

5.1 Continuation into Parking Orbit

These results are presented first since they provide asymptotes for the direct entry case. That is, attainment of a parking orbit is equivalent to infinite range; thus, as the time of abort approaches that at which orbit can be attained, the maximum range for direct entries must increase asymptotically.

The results, based upon the assumed performance, weights, and nominal launch trajectory are that orbit can be attained any time subsequent to t = 407 sec (measured from liftoff) when using the S-IVB or subsequent to t = 488 sec when using the SM. The latter figure includes an allowance of 1500 pounds of propellant for a subsequent SM deorbit maneuver. The infinite range asymptote for direct entry, however, is based upon the ability to attain orbit without any deorbit allowance. This occurs at t = 484 sec.

The difference in performance between the S-IVB and SM is due to two factors: (1) the higher ΔV available from the S-IVB (13,400 fps versus 10,900 fps), and (2) the higher thrust-to-weight ratio when using the S-IVB. The importance of the thrust-to-weight ratio in this case is due to the problem of holding altitude. On the nominal launch trajectory, the vehicle flies at or near orbit altitude during most of the S-II burning period. Consequently,

the thrust acceleration vector must compensate for the difference between gravity and centrifugal force. Since the SM has a lower thrust-to-weight ratio, its thrust must be oriented closer to the vertical and, consequently, its ΔV loss is greater. Thus, when aborts are initiated at the critical times of 407 and 484 sec respectively, the S-IVB and SM suffer ΔV losses of approximately 3,000 fps and 4,000 fps respectively in attaining orbital speed.

5.2 Direct Entry with S-IVB

The results for direct entry with the S-IVB are shown in Figure 1. The upper and lower curves (solid lines) represent the maximum and minimum ranges calculated. The maximum range asymptotically approaches infinity as time of abort approaches 407 sec, the earliest abort time for which orbit can be attained. The dotted curves are taken from Reference 1 and represent direct entry without propulsion. The entry trajectories following the powered orbits were based upon L/D = +0.5.

The data in Figure 1 starts at t = 180 sec, which is 30 sec after S-IC thrust termination (tentatively the time for LES jettison) and continues to t = 546 sec which is the nominal S-II cutoff time.

The curves show that the maximum range at t = 180 is slightly greater than the minimum range at t = 546. This means that a single recovery point would suffice for aborts initiated at any time within this period. This

point would be between 1,900 and 1,950 nautical miles down range from Cape Kennedy. One additional point would suffice for aborts initiated during S-IVB nominal first burn: e.g., this point could be the minimum range point using the SM when the abort is initiated just at the instant of injection into orbit (t = 700 sec). Since the SM has orbital capability during the entire S-IVB burn, this point could always be reached during this period. Thus, two recovery points for aborts subsequent to LES jettison are necessary if the S-IVB is used as an abort stage.

5.3 Direct Entry with the SM

The performance capability of the SM for direct entries is shown in Figure 2. Until the CM/SM approaches orbital capability at t = 484, its minimum and maximum ranges are severely limited because its thrust-to-weight ratio is not adequate to keep it above 400,000 altitude until all available propellant can be used. For most of the cases studied, in fact, the SM was able to use less than half of its propellant. The result is that the maneuvering capability is substantially less than that of the S-IVB.

Note that the difference between the maximum and minimum range reaches a minimum at a time of abort midway between S-II ignition and burnout. This is because the time between abort and entry reaches a minimum due to two counteracting effects. The first is that as

the time of abort increases, the flight path angle is decreasing towards horizontal. This results in a tendency to lower the altitude of the abort path. The counteracting effect is that as the time of abort increases, the velocity at the start of the abort increases. Thus, the initial centrifugal force increases with increasing abort times, resulting in a tendency to increase the altitude of the abort path.

Two different 'minimum' range curves are shown in Figure 2; one corresponding to entries with maximum L/D, and the other entries with the value of L/D which results in a 10 g entry. The latter gives shorter ranges than the former. However, the differences between these minimum range curves do not appear great enough to affect the number of recovery points required. The number of recovery points required is determined as follows. Starting at the time of LES jettison, a recovery area located at 780 nautical miles down range (the maximum possible range at t = 180 seconds) of Cape Kennedy can be reached at all flight times up to t = 310; at this time the minimum possible range exceeds 780 nautical mile.

Similarly, the maximum possible range at t = 310 seconds is about 1,050 nautical mile, and this point can be reached on aborts initiated until t = 375 seconds, when it is less than the minimum possible range. In this

manner it can be determined that a total of five recovery points are required; the locations, assuming entries with maximum L/D, are given in the following table:

Time of Abort	Recovery Point (Range)
180 - 310 seconds	780 nautical mile
310 - 375	1,050
375 - 425	1,290
425 - 477	1,590
477 - 700	3,100 or greater

With the data shown in Figure 2, the only difference between the recovery point requirements for (L/D) maximum entries and 10 g entries is that in the latter case the fifth recovery point can be 2,630 nautical mile or more down range from Cape Kennedy; whereas, in the former case it must be at least 3,100 nautical mile down range. However, if the asymptote shifted slightly to the right or the maximum range curve approaches the asymptote slightly less steeply, a sixth recovery point may be required.

5.4 Sensitivity to Steering Program

The data of Figures 1 and 2 were computed using pitch programs in which the angle between the thrust vector and the local horizon is constant. This type of program is especially suitable when either

visual cues or a horizon sensor is used as the attitude reference. However, if space-fixed reference such as an inertial platform is to be used, then a constant pitch angle with respect to a fixed direction in space would be appropriate. For comparisons, therefore, sample data were obtained using a constant space-fixed pitch attitude for the case of abort just at the moment of nominal orbital injection (t = 700 sec). This is the case in which a fixed pitch angle with respect to the initial horizon will differ most from a fixed attitude with respect to the local horizon since the local horizon is changing most rapidly at this time. The result is that for direct entries, the minimum range using space-fixed pitch attitude is about 30 nautical miles less than for fixed pitch angle with respect to the local horizon. A difference of this magnitude is of no consequence for present purposes. This is therefore taken to indicate that the difference in terms of vehicle performance between the two programs is not important.

5.5 Sensitivity to Ignition Delay Time

The ignition delay time, i.e., the length of time which occurs between the termination of nominal powered flight and the beginning of the powered abort, depends on many factors. These factors include the method of separation, required separation distance before ignition, pitch-up of the vehicle to the proper attitude, engine chilldown (if necessary), thrust build-up time for the engine and others. The data in Figures

1 and 2, as well as the data for continuation into orbit, were based upon zero delay time for the SM and 10 sec ignition delay for the S-IVB. The question arises as to how much the performance is degraded by long ignition delays since the time available before entry is limited. As a representative case, therefore, direct entry minimum range aborts with the SM were calculated for t = 546 (nominal S-II burnout time) with an assumed one minute ignition delay. In this case, with L/D = 0.5, the minimum range is about 138 nautical mile greater than when there is no delay.

The performance penalty for minimum range, in this case resulting from a one-minute ignition delay, can be largely nullified by entering with a lower L/D. That is, by flying with an L/D corresponding to that for a 10 g entry, the total range following a one-minute delay is only about 24 nautical mile greater than that when there is no delay and entry is carried out with L/D = 0.5.

This selected case (t = 546 sec) is believed to be representative for SM aborts in general. At earlier abort times, the delay time represents a greater percentage of the time between abort and entry. However, since the maneuvering capability is less to begin with, the absolute penalty in maneuvering capability should not be much different than the selected case.

For later abort times, the time to entry is greater and, therefore, the performance penalty due to ignition delay is less.

The penalty for ignition delay of the S-IVB beyond that assumed (ten seconds) will generally be less than with the SM because of the higher thrust-to-weight ratio and, therefore, greater time to entry using the S-IVB.

It is therefore concluded that on direct entries, the present results would not be significantly different for ignition delays of up to at least one minute.

The effect of a one minute ignition delay on the capability of the SM to continue into orbit was also investigated. The result is that the earliest abort time for which the SM/CM can reach orbit is increased from about 488 sec to about 509 sec.

5.6 Sensitivity to Pitch Angle and Thrust Cut-Off Time

The sensitivities of range to errors in pitch attitude and thrust cut-off time during powered aborts depend on the time of abort and which propulsion system is being used. Examination of the data indicates that the maximum sensitivities which occur are about 60 nautical mile per degree of pitch angle error and 60 nautical mile per second error in thrust cut-off time. At most times, however, the sensitivities are actually an order of magnitude or more lower than these figures.

6.0 DISCUSSION OF RESULTS

6.1 Possible Restriction of Aborts to Posigrade Maneuvers

The foregoing results have not included any restrictions on the pitch attitude of the S-IVB or SM. Implicit in these results was the use of retrograde* maneuvers at some times, since this is necessary whenever the range is to be less than if no propulsion were used.

Following a retrograde maneuver, it is necessary to maneuver the vehicle out of the path of the CM in the limited time prior to entry, and it might therefore be desirable to eliminate such maneuvers from operational planning. It is possible to do this and still limit the number of recovery points to two. Referring to Figure 1, it is seen that if a recovery point is 1,950 nautical mile down range, then a posigrade maneuver must be executed to reach this point for aborts initiated at any time up to t = 520 sec. At

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* The term retrograde and posigrade are used herein to indicate any maneuvers which result in loss or increase of range respectively. This does not necessarily mean that the thrust vector is parallel to the velocity vector, so that, in general, a pitchup is required at the start of abort even for posigrade maneuvers.

this time, the 1950 nautical mile point can just be reached on a direct entry without any propulsion. From this time on, orbit can be attained with either the S-IVB or SM and a second recovery point would suffice.

6.2 Possible Use of Open Loop Control for Aborts

Guidance implementation, either automatic or manual, would be greatly simplified if an open loop mode can be used for aborts. In the Saturn guidance equations, for example, this would imply that the polynomials for the pitch angle and thrust cutoff time would simply be functions of the time of abort. Going one step further in accuracy would be to make the pitch angle and thrust cutoff time functions of the actual position and velocity vectors at the time of abort, thereby accounting for dispersions from the nominal launch trajectory. To use the guidance polynomials in closed loop, on the other hand, it is not only necessary to derive polynomials which are functions of instantaneous position, velocity, time and thrust/weight ratios, but in addition it would probably be necessary to have the coefficients in the polynomials vary with the time of abort.

The sensitivities to pitch angle and cutoff time which were discussed in the section on Results (5.0) are small enough so that impact point errors

without closed loop control may be acceptable. It is therefore recommended that the possibility of open loop control should receive further study.

The previous remarks apply to direct entries The problem is more difficult when considering continuation into parking orbit, since, in this case, at least three pitch program parameters must be specified: Initial pitch angle, pitch rate, and burning time. In addition, orbits other than the nominal parking orbit may be acceptable for abort purposes. Further study of this mode is also recommended.

7.0 CONCLUDING REMARKS

The results of this report are based on a fixed launch azimuth. For actual LOR operations, as contrasted to earth orbital operations, it may be necessary to vary the launch azimuth as a function of launch time. This will somewhat complicate the recovery problem since the launch track over the earth's surface will also change with launch time. Nevertheless, the results of this study should still apply, but in terms of recovery areas rather than recovery points.

Other factors such as lateral maneuvers and dispersions from the nominal launch trajectory have been neglected. Such factors, together with vehicle data changes which will continue to occur, preclude a precise and definitive study at this early date. In addition, many questions about failure modes and operational problems must be resolved. However, it is hoped that the results reported herein will provide a basis for preliminary discussion.

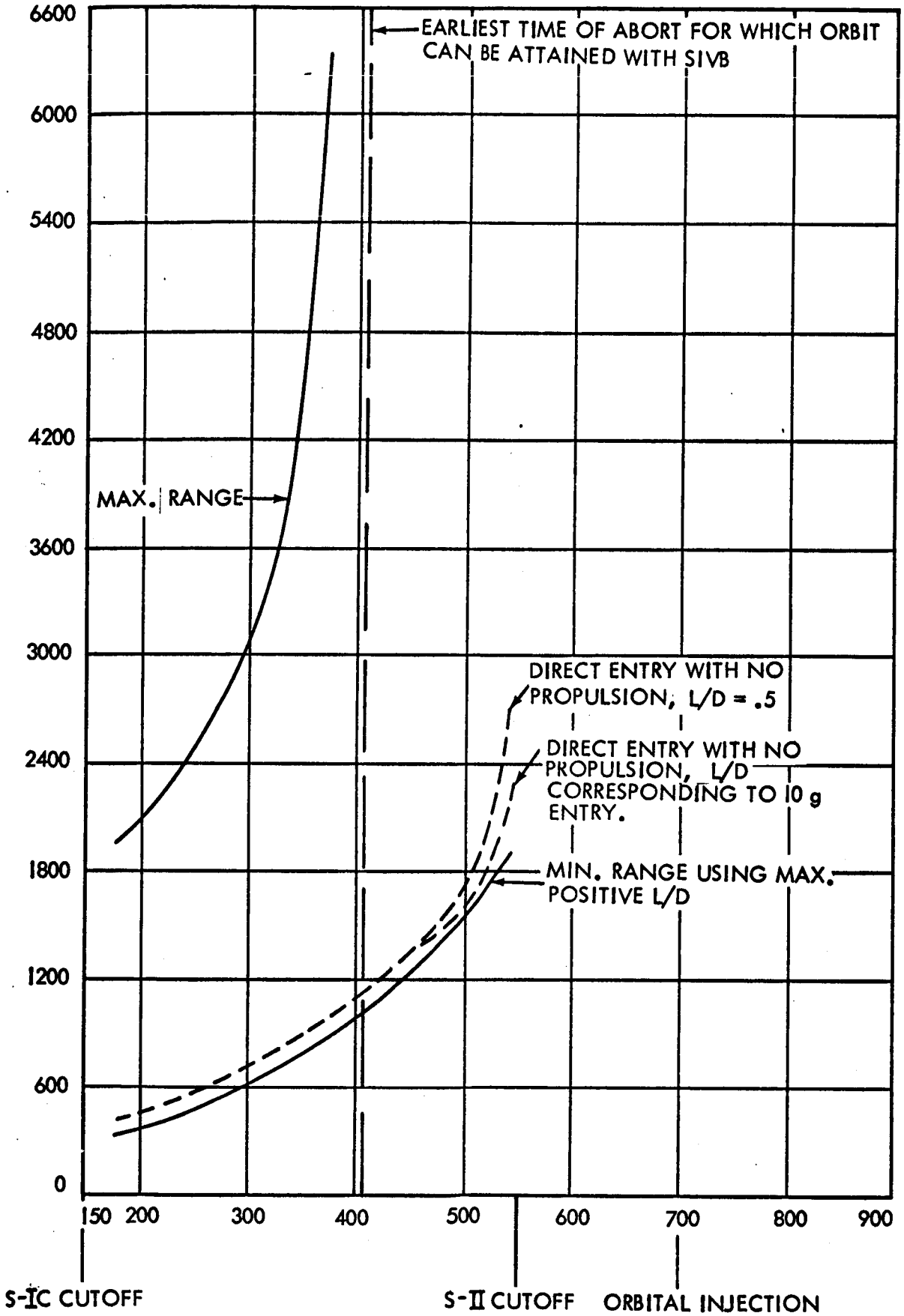

FIGURE 1 DIRECT ENTRY POWERED ABORTS USING SIVB

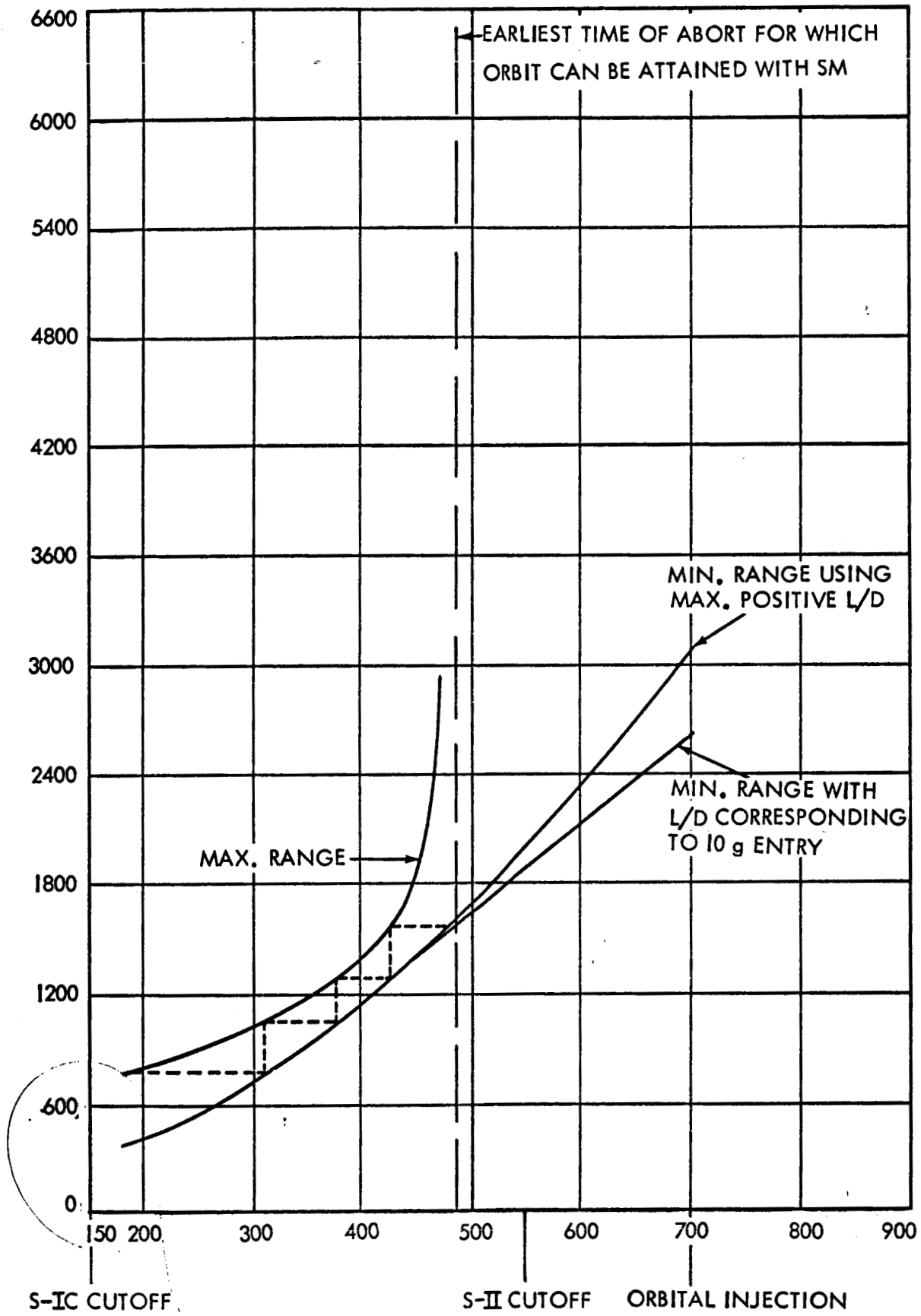

FIGURE 2 DIRECT ENTRY POWERED ABORTS USING SM

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